Optimal Allocation Method of Phase Shifting Transformers Based on Power Flow Controllability(潮流制御性に基づく位相調整器群の最適配置決定法に関する研究)

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論 文 内 容 要 旨

Since the request for the cheaper power charge as one of the preventive measure against vacuuming industry, Independent Power Producer (IPP) was systematized. In addition that the first recruit was taken place in 1996, a new generation started.

The reconstruction and deregulation of electric utilities is very large and complex. Approximately, it can be divided into basically four main stages or processes as following and shown in figure 1.

Monopoly at all levels　Model Ⅰ

All levels were known as "generation", "transmission", and "distribution". This shape of electric utility was being spreading universally as the administration of electric power companies in Japan before the bidding competition had taken effect.

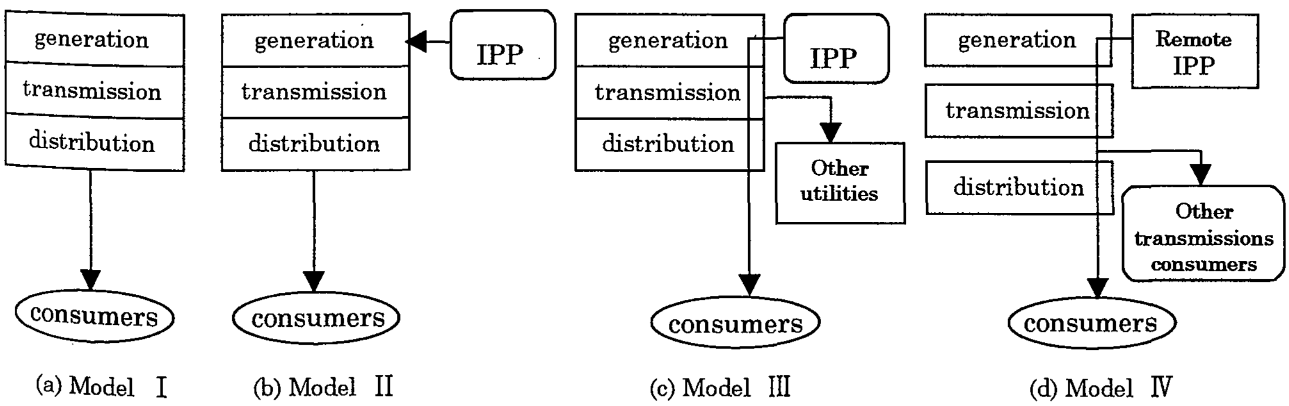


Figure 1. The reconstruction and deregulation of electric utilities.

Purchasing agency Model II
For urging the competition in the generation fields, the independent purchasers—power companies can buy electricity from the desiring generating utilities. In this shape of electric utility, the power purchasers own the monopoly on both the transmission grid and the sale to terminal consumers as the shape of power companies in Japan and Taiwan since the IPP bidding had been introduced.

Wholesale competition Model III
The companies can sell electricity in retail which buy power from the existed power companies and generating utilities in wholesale, where the transmission fields are not opened to access. That is, the residential monopoly is still held by the distribution companies. The assumed system is existing in EPACT (the Energy Policy Act of 1992) in the United States and similar to the system functioned in the Kingdom when the electric utility was privatized in 1990.

Retail competition or direct access Model IV
All of the consumers can buy electricity from any of power suppliers. Kingdom, Norway, Chili, Victoria in Australia, and California in the United States shifted to such a power business.

Extensive efforts are being made to create a more competitive environment for electricity markets in order to promote greater efficiency. Thus, the power industry faces many new problems, with one of the highest priority issues being reliability that is, bringing a steady, uninterruptable power supply to all electricity consumers. The restructuring and deregulation of electric utilities, together with recent progress in technology, introduce unprededential challenges and opportunities for power systems research and open up new opportunities to young power engineers.

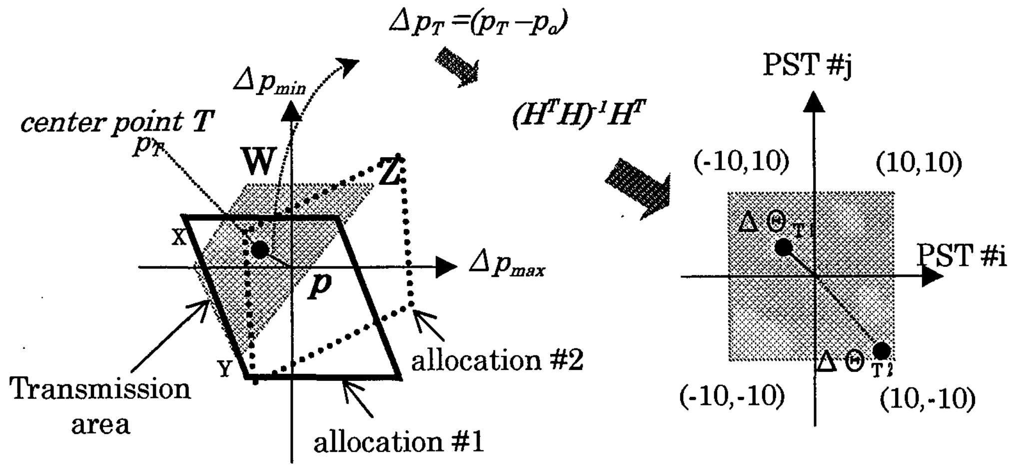
Due to the network open access is promoting the power wheeling, power congestion or parallel flow problems tend to occur for the simultaneous transactions of electric power in power networks. To solve such problems and add new freedom to power transmission without changing power dispatch, one of the strategies is to control power flow by Phase Shifting Transformers (PSTs).

This thesis proposes a novel method to determine the optimal allocation of multiple PSTs. By which PSTs can modulate power flow distribution to the target flow pattern easily and effectively. The method is, at the first step, the minimum number of PSTs necessary and allocation candidates to which can be determined by the concept of co-tree in graph theory. Therefore, all loop flows in an entire network are controllable. Since the sensitivity of line flow fluctuation to PSTs control angles is driven into a matrix in this thesis. Through eigenanalysis of the matrices, the features of controllable power flow profiles and inherent modes to various allocation candidates can be identified as the eigenvalues and eigenvectors of the matrices. Next, by available of the features, the transmission margin of an entire network to a certain loading situation can be known. Finally, by judging the relationships between each power flow profile, transmission margin and control target, the optimal allocation can be found.

A consideration of how determining the PSTs allocation is described in figure 2. The power flow modulation by multiple PSTs corresponds to the mapping of a control angle θ of PSTs into a power flow profile p_f. The mapping is done through the matrix H which is composed of the sensitivities of line flows to the control angle. The features of power flow profiles which can be controlled by PSTs depend on the characteristics of the matrix H, that is, the allocation of the PSTs. In this thesis, it is clarified that the features of controllable profiles can be extracted from the eigenvalues and eigenvectors of a matrix (H^TH) (^{T} : transposition) and those features are applicable to the determination of PSTs' allocation.

Figure 2(a) shows the relationships of control target T and controllable power flow profiles to various allocations. The origin p_o represents the flow pattern of the power network without control. The point p_o exists in marginal transmission area means that the transmission network is operating in a stable situation. Contrarily, if it was not, then an overloading is occurring in the entire network. Therefore, for any purposes as to unwind the parallel flows etc., the control target T can be set and judged in the consideration of marginal transmission area.

On the other hand, since the flow modification Δp_T to the target flow pattern p_T can be known by Eq.(1), through Eq.(2), the control angles $\Delta\theta_T$ for various PSTs allocations can be found and which are the absolute solutions.



(a)Controllable flow area

(b) Controllable angles

Figure 2 An example of marginal transmission area and controllable flow area for the evaluation of control angles spaces.

$$\Delta p_T = p_T - p_o \tag{1}$$

$$\Delta\theta_T = (H^T H)^{-1} H^T \Delta p_T \tag{2}$$

object to $\min\|\Delta\theta_{Ti}\|_{i=1,2,3...}$ (3)

In Eq.(3), the optimal allocation can be found which corresponds with the minimum control angles to the control target. By Eq.(2), the control angles obtained.

This thesis is organized into 6 chapters and 3 appendixes. Each chapter begins with an introduction describing the topics.

Chapter 1 is a brief overview of the development of power systems and the movements of reconstructing and deregulating in electric utilities in the United States and Japan, respectively.

Chapter 2 addresses the resulting of parallel flows and briefly describes the key factors influencing bulk transmission utilization. For resolving parallel flow and stability control, the ability to control impedance or phase angle is obviously the most important need.

Chapter 3 is devoted to propose a novel method to identify the power flow profiles, which can be controlled by multiple PSTs. In the proposed method, the minimum number of PSTs necessary for the control of power flow in an entire network is determined. The features of controllable power flow profiles with respect to each allocation are extracted as the eigenvalues and eigenvectors of a matrix. The extracted features are applicable to the determination of PSTs allocation from the viewpoint of flexible power flow control in network open access environments.

In **Chapter 4**, those extracted features are availed to identify the marginal transmission capacity of an entire network, under a certain loading situation. Examining the correlation of various controllable power flow profiles and marginal transmission capacity, the optimum PSTs allocation can be determined. A satisfactory prediction performance is attained as show in the simulation results, showing the effectiveness of the proposed method.

Chapter 5 proposes a concept to improve the transmission capacity of the network by phase shifters while the contingency occurs in a transmission line. The concept is that in advance, the power flow of the line where a contingency is considered to occur is shifted to other lines by PSTs.

Chapter 6 is to conclude this thesis and further indicate the research topics for future study.

審査結果の要旨

1990年代に英国と米国を中心に推進された電力産業の構造変革は、新規発電業者による電力取引を増大させ、電力潮流制御の複雑化と、送電限界に達する重潮流の発生を招いている。日本においても、2000年3月から、一部の需要家を対象として送電網利用の自由化が実施されるため、電力システムの信頼度維持が懸念されている。

筆者は、これらの電力潮流問題に注目し、電力システムの信頼度維持を目的とした位相調整器群の最適配置について研究を行った。本論文はその成果をまとめたもので、全編6章よりなる。

第1章は緒言であり、本研究の背景と目的を述べている。

第2章では、送電網利用が自由化された状況で発生する、パラレルフローと呼ばれる電力潮流問題を概観し、この問題の解決策として、位相調整器群による潮流制御が有効であることを論じている。

第3章では、位相調整器群の配置と制御可能な潮流パターンの関係を明らかにしている。すなわち、回路の木と補木の性質を利用して位相調整器の最小必要台数と配置を決定し、それぞれの配置において位相調整器の制御性を表す感度行列を導き、その固有値解析から最も制御感度の高い潮流パターンを見出す方法を考案した。この潮流パターンを従来の潮流計算で探索する場合、位相調整器台数をm、制御角可変タップ数をnとするとn^m回の計算を必要とするが、提案手法によると、一回の潮流計算と一回の固有値解析から決定できる。これは有用な成果である。

第4章では、電力システムの送電余裕の均等化を目的とした位相調整器群の最適配置決定法を提案している。送電網利用が自由化された電力システムでは、特定の線路のみが重潮流化し、信頼度が低下する。信頼度を維持しつつ既存の送電設備を効率良く利用するためには、送電余裕が均等になるような位相調整器群の最適配置が重要な課題となる。ここでは、第3章の手法に基づき、位相調整器群の配置と制御感度の関係を利用した最適配置決定法を提案した。これを30母線41線路の電力システムに適用した結果、送電余裕の均等化を実現する位相調整器の必要台数と配置、およびその制御角を容易に決定できることが明らかになった。これは実用上有用な成果である。

第5章では、電力システムの過渡安定度の向上を目的とした位相調整器群の最適配置を論じている。すなわち、位相調整器群を適切に配置することにより送電限界を高めることが可能であることを指摘し、第3章および第4章で開発した配置決定法が電力システムの動特性を考慮した配置決定にも適用可能であることを明らかにしている。

第6章は結言である。

以上要するに本論文は、電力潮流の制御性に着目して位相調整器群の最適配置を系統的に決定する手法を明らかにし、今後の電力システムが直面する電力潮流問題の解決策の基礎を与えたもので、電力システム工学の発展に寄与するところが少なくない。

よって、本論文は博士（工学）の学位論文として合格と認める。